# 12 Extension of Shelf Life and Control of Human Pathogens in Produce by Antimicrobial Edible Films and Coatings

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## Biopolymers Used for Edible Films and Coatings

Components of edible films and coatings can be divided into three categories: hydrocolloids, lipids, and composites. Hydrocolloids include proteins and polysaccharides, such as starch, alginate, cellulose derivatives, chitosan, and agar. Lipids include waxes, acylglycerols, and fatty acids (Min and Krochta 2005). Composites contain combinations of both hydrocolloid components and lipids. The choice of formulation for edible film or coating is largely dependent on its desired function—such as biodegradability, edibility, aesthetic appearance, and good barrier properties against oxygen—which varies based on the composition of the film (Cha and Chinnan 2004). In addition, edible films and coatings can serve as supports containing antimicrobial, nutritional, and antioxidant substances (Gennadios and others 1997).

Depending on their composition, the functionality of edible film and coating materials may vary because each component confers different properties on the composite matrix. Films made of hydrocolloids (polysaccharides or proteins) usually have strong mechanical and gas barrier properties, but also have poor water vapor barrier properties and high permeability to moisture. In contrast, films composed of lipids exhibit good water vapor barrier properties, but they tend to show poor mechanical strength and high oxygen permeability. Combining these components into one matrix allows them to physically and/or chemically interact and may result in films with improved properties (Diab and others 2001). For example, fruit-based edible films can be made with excellent oxygen barrier properties, but not very good moisture barrier properties. Combining fruit purées with various gelling agents (such as alginate) improves the water barrier and tensile properties of the resultant fruit-based films (Mancini and McHugh 2000).

Polysaccharides are commonly used for edible films because their film-forming properties are derived from cellulose, starch, alginate, and their mixtures. A plasticizer is normally added to increase the flexibility of the film, and occasionally it is used only to facilitate the polymer processing. The most commonly used plasticizers in starch-based films are polyols, such as sorbitol and glycerol. They are frequently added into edible films to relax the intermolecular forces and increase the mobility of the polymeric chains to improve flexibility (Durango and others 2006). Glycerol is a low–molecular-weight nonvolatile substance that is often used to modify the mechanical properties of hydrophilic films. The addition of glycerol into films reduces internal hydrogen bonding between polymer chains while increasing molecular volume, resulting in an improvement in film flexibility (Mali and others 2006).

The development of films from water-soluble polysaccharides has led to promising new types of materials for the preservation of fruits and vegetables, because these biopolymers show selective permeability to $O_2$ and $CO_2$. These films reduce $O_2$ levels and increase $CO_2$ levels in the internal atmospheres of coated fruits and vegetables and reduce respiration rates, thereby extending the shelf life of fresh produce in a manner similar to modified/controlled atmosphere storage (Diab and others 2001).

## Edible Coatings for Fresh Fruits and Vegetables

Edible coatings are continuous biopolymeric matrices formed as films and directly applied on the exterior surface of fresh fruits and vegetables. Edible wax coatings have been used in fresh produce since the 1930s in the United States to reduce moisture loss and improve glossiness (Park 1999). Edible coatings are prepared as solutions and emulsions from proteins, polysaccharides, and lipids and are applied on produce surfaces by different mechanical procedures, such as dipping, spraying, and brushing (Avena-Bustillos and others 1994, 1997), or by electrostatic deposition (Amefia and others 2006). The chemical and physical characteristics of the edible coating solution and the coating thickness, homogeneity, and adhesiveness depend on the surface structure and morphology of the fruits and vegetables (Miller and Krochta 1997). Produce skin pores, trichomes, and natural waxes all affect the oxygen, carbon dioxide, and water permeability properties of the coatings and influence their capability to maintain freshlike quality of produce (Avena-Bustillos and others 1994; Park 1999). Coating matrices also can incorporate active antimicrobial agents to provide produce with microbial produce stability and protect against foodborne outbreaks.

## Edible Films for Fresh Fruits and Vegetables

Edible films are thin films prepared from edible material that act as a barrier to control moisture, oxygen, carbon dioxide, flavor, and aroma exchange between food components or with the atmosphere surrounding the food and also to protect the product, extend its shelf life, and improve its quality (Suyatma and others 2005). For edible films to be used in foods, there are several requirements to be considered, such as appropriate gas and water barrier properties; good mechanical strength and adhesion; reasonable microbial, biochemical, and physicochemical stability; effective carrier capability for antioxidant, flavor, color, nutritional, or antimicrobial additives; safety for human consumption (free of pathogenic microorganisms and hazardous compounds); acceptable sensorial characteristics; low cost of raw materials; and simple technology for production (Debeaufort and others 1998).

Generally, an *edible film* is defined as a preformed thin layer or solid sheet of edible material placed on or between food components (Krochta and De Mulder-Johnston 1997). Edible films can be used as wraps or pouches for food. Wrapped films were shown to be advantageous over traditional coatings for retarding moisture and color losses in fresh-cut apples during storage (McHugh and Senesi 2000). Edible films can also enhance or improve food's appearance and nutritional value.

The applications of edible films to fresh fruits and vegetables have received increasing interest because these films can serve as carriers for various antimicrobial compounds that can reduce the risk of pathogen growth. Preservatives, acidulants, antioxidants, and antibiotic compounds can be added to edible films to reduce surface microbial populations on foods and enhance oxygen-barrier properties. Edible films can also enhance food nutritional value and improve the appearance of foods. A greater emphasis on safety features associated with the addition of antimicrobial agents is the next area for development in edible films technology (Cha and Chinnan 2004).

## Fruit and Vegetable-Based Edible Films

McHugh and others (1996) developed the first edible films made from fruit purées and characterized their water vapor and oxygen permeability properties. Fruit-based edible films were excellent oxygen barriers, particularly at low to moderate relative humidities. McHugh and Senesi (2000) coated apple pieces by dipping into solutions and then drying or wrapping in preformed apple-based edible films. Increasing the lipid concentration of the films significantly improved its moisture barrier properties. Water vapor permeability values were reduced from 325 to 69 g-mm/kPa-d-$m^2$ through the addition of lipids. Apple-based wraps significantly reduced moisture loss and browning in fresh-cut apples, retaining color for 12 days at 5 °C. Wraps were significantly more effective than coatings of the same composition (McHugh and others 1997).

In addition to providing antimicrobial properties, fruit- and vegetable-based edible films can benefit consumers in other ways. For example, although the USDA Food Guide Pyramid recommends that mature adults consume 2–4 servings of fruit per day, less than half of Americans meet these dietary recommendations. Because consumers demand convenience and variety, there is a need to provide access to fruit products in new, innovative forms. Incorporation of fruit purées into edible barrier films can help meet these needs. Fruit films, due to their low moisture levels, are concentrated sources of natural nutrients and can impart appealing colors and flavors.

Apple and tomato purées have been used to prepare model edible films in recent studies to incorporate antimicrobial plant essential oils (Rojas-Graü and others 2006, 2007a; Olsen and others 2008). Undoubtedly, the results can be extrapolated to other fruit- and vegetable-based films. Based on the interest in the use of fruit and vegetable films, a commercial partner, Origami Foods, has begun to commercialize fruit- and vegetable-based edible films.

A potential application of fruit- and vegetable-based edible films is the controlled release of volatile active antimicrobial compounds from the natural essential oils of plants. Because plant essential oils and some fruit and vegetable products are commonly found in combination food products such as pizza, which contains tomato, basil, and oregano, it is anticipated that the flavors of plant essential oils and other antimicrobial phytochemicals added to the fruit and vegetable films will be readily acceptable to consumers (Rojas-Graü and others 2007b). Edible films can then be incorporated into conventional packaging systems (Koide and Shi 2007) for fresh and fresh-cut fruits and vegetables with a dual purpose as edible and antimicrobial components.

## Edible Film Casting Methods

Despite the growth in research on edible films, the extent of commercialization has not progressed as significantly. Manufacturing processing methods and the resultant mechanical and water barrier properties of edible films must be improved for practical use (Arvanitoyannis and Gorris 1999). Edible films are commonly produced via a solution casting process where the films are dried from 2 to 12 h. Shorter drying times allow the formation of films with no significant microbial contamination. Knowledge of critical control points is necessary to reduce the risk of microbial growth. The quality of the starting materials, as well as the use of heat and good sanitation during casting and drying, is necessary to ensure safety (McHugh and Olsen 2001).

Most of the edible films made have been cast using inefficient technologies and there is a need to develop more efficient methodologies for the mass production of edible films. Recently, we reported significant differences in physical and antimicrobial properties of apple- and tomato-based edible films made by continuous casting under infrared heating in a pilot plant lab coater and by a batch drying process done overnight under ambient air (Du and others, 2008a,b). The continuous method for film casting was more suitable for large-scale production of fruit- and vegetable-based edible films than the batch method. The tendency of volatile active antimicrobial compounds to evaporate during casting at high temperatures can be compensated by manipulating the formulation to achieve an appropriate final concentration of the antimicrobial compound in the dried films (Du and others, 2008a,b).

## Antimicrobial Plant Essential Oils in Edible Films

Naturally derived biological compounds and other natural products may have application in controlling pathogens in produce. They have varied antimicrobial and antioxidant properties that can break down cellular membranes and disrupt biosynthetic pathways of microorganisms (Benaventi-García and others 1998; Bowles and Juneja 1998; Bowles and others 1995). The use of edible films as antimicrobial carriers represents an interesting approach for the external incorporation of plant essential oils and other phytochemicals onto food system surfaces. The agents can then diffuse into the food to control target microorganisms. The antimicrobial activity of plant essential oils is confined to a number of small terpenoid and phenolic compounds, which are known to exhibit antibacterial or antifungal activity.

Recent studies have shown that essential oils of oregano (*Origanum vulgare*), thyme (*Thymus vulgaris*), cinnamon (*Cinnamon casia)*, lemongrass (*Cymbopogon citratus*), and clove (*Eugenia caryphyllata*) are among the most active antimicrobials against strains of *Escherichia coli* (Dorman and Deans 2000; Friedman and others 2002; Hammer and others 1999; Smith-Palmer and others 1998). Although the effectiveness of all these compounds has been widely reported, carvacrol (a major component of the essential oils of oregano and thyme) appears to have received the most attention from investigators. Carvacrol is generally regarded as safe (GRAS) and used as a flavoring agent in baked goods, sweets, ice cream, beverages, and chewing gum (Fenaroli 1995). However, widespread application of plant essential oils in food systems has been limited by the incompatibility of their strong flavors with some foods. Plant essential oils and their components are compatible with the sensory characteristics of fruits and vegetables and have been shown to prevent bacterial growth.

Among the complex constituents of citrus essential oils, the terpene citral is known to have strong antifungal properties (Rodov and others 1995). In addition, cinnamon oil and its active compound (cinnamaldehyde) also have been tested for their inhibitory activity against *E. coli* (Friedman and others 2004a,b; Helander and others 1998).

Phenolic compounds are found in numerous plant species (Walsh 2003). These compounds appear to be involved in the defense of plants against invading pathogens, including bacteria, fungi, and viruses. Phenolic compounds present in teas (Friedman and others 2005, 2006), pigmented rice brans (Nam and others 2006), and most fruits and vegetables (Shahidi and Naczk 2004) are also reported to exhibit antimicrobial effects (Friedman and others 2003, 2005). Some of these have been incorporated in edible films (Cagri and others 2004).

Studies on the antibacterial activity of oregano, lemongrass, and cinnamon plant essential oils and their major components carvacrol, citral, and cinnamaldehyde in apple purée film-forming solutions against the foodborne pathogen *E. coli* O157 : H7 and *Salmonella enterica* show that oregano oil as well as its major component carvacrol killed *E. coli* O157 : H7 and *S. enterica* practically on contact (3 min). The order of antimicrobial activities was as follows: carvacrol > oregano > citral > cinnamaldehyde > lemongrass > cinnamon oil (Friedman and others 2004). The evaluation of the physicochemical properties of films made from apple slurries revealed no adverse effect of the additives on water vapor permeability properties (Rojas-Graü and others 2006, 2007a). The antimicrobial films showed good oxygen barrier properties and their tensile strength did not differ significantly from control films without added antimicrobials.

## Physical Properties of Edible Films Containing Plant Essential Oils

The ideal characteristics of an edible film would be low water vapor permeability and high mechanical strength. The physicochemical properties of edible films (e.g., color, tensile strength, water vapor, and oxygen permeability) relate to the ability of the coating to enhance the mechanical integrity of foods, inhibit moisture loss and oxidative rancidity, and improve final-product appearance (Debeaufort and others 1998). A complete analysis of both antimicrobial and physicochemical properties is important for predicting the behavior of antimicrobial edible films in the food system (Cagri and others 2001; McHugh and Krochta 1994b).

McHugh and others (1996) demonstrated that apple-based edible films were not very good moisture barriers and that the addition of lipids could potentially improve the water barrier properties of fruit-based films. Rojas-Graü and others (2006) found that water vapor permeability decreased when the proportion of the hydrophobic compounds increased in apple-based edible films, this effect being more prominent when oregano oil was used in the composition of the films.

Adding carvacrol addition to apple purée edible films resulted in significant decrease in film water vapor permeability. Water vapor transfer generally occurs through the hydrophilic portion of the film; thus, water vapor permeability depends on the hydrophilic-hydrophobic ratio of the film components (Hernández 1994). Water vapor permeability increases with polarity, unsaturation, and degree of branching of the lipid, but it also depends on the water absorption properties of the polar part of the film (Gontard and others 1994).

The chemical nature of the essential oils also plays an important role in the barrier properties of edible films. Differences observed in these properties can be explained by the hydrophobicity of the plant essential oils. Carvacrol, a phenolic compound containing an alcohol group in its chemical structure, seems to be a good barrier compared to aldehyde compounds (e.g., cinnamaldehyde, citral) because the hydroxyl group has less affinity for water than for the carbonyl groups. Carvacrol then offers the possibility not only to enhance antimicrobial efficiency but also to improve water barrier properties of edible films.

McHugh and Senesi (2000) suggested that lipids with lower melting points, such as vegetable oil, oleic acid, and myristyl alcohol, exhibit superior barrier properties presumably due to their smooth structure and lack of channels between crystalline platelets through which water could migrate easily. The incorporation of emulsion droplets in the film increases the distance traveled by water molecules that diffuse through the film, thereby decreasing water vapor permeability (McHugh and Krochta 1994c).

McHugh and others (1996) demonstrated that apple-based edible films are excellent oxygen barriers, particularly at low-to-moderate relative humidities. An apple purée edible film was a good oxygen barrier, exhibiting low oxygen permeability values of $22.6 \pm 1.3\,cm^3 \mu m/m^2$-d-kPa. The oxygen permeability values of this film increased as higher amounts of plant essential oils were incorporated. McHugh and Krochta (1994a) indicated that films containing lipids exhibit relatively poor oxygen barrier properties. The oil chemical nature plays a major role in the barrier properties of edible films. Lower oxygen permeability was observed in films that contained oregano, lemongrass, and cinnamon oils than in those that contained its antibacterial compounds carvacrol, citral, and cinnamaldehyde, respectively (Rojas-Graü and others 2006, 2007a).

Tensile strength is one of the most common indicators of the mechanical property of an edible film. It expresses the maximum stress developed in a film specimen during tensile testing (Gennadios and others 1994). The incorporation of plant essential oils in apple-based edible films caused a significant increase in tensile strength, % elongation, and elastic modulus of the film. These differences could be related to differences in their polarities. These results are in agreement with those obtained by Pranoto and others (2005), who studied the physical and antibacterial properties of alginate edible film with garlic oil. Elongation at break is a measure of the film stretchability prior to breakage (Krochta and De Mulder-Johnston 1997). Zivanovic and others (2005) studied the antimicrobial and physicochemical properties of polysaccharide (chitosan) films enriched with essential oils. They observed a decrease in tensile strength and an increase in elongation percentage when the essential oils were introduced into the films. This behavior also was observed by Bégin and Van Calsteren (1999).

## Evaluation of Antimicrobial Activity of Volatile Components

The growth of microorganisms on the surface of a food is a key factor affecting the safety and/or spoilage of food products (Padgett and others 1998). The direct addition of an antimicrobial additive into foods might reduce its effectiveness, due to the presence of substances that interact with it, to reduce its antimicrobial effect (Durango and others 2006). The use of antimicrobial films could be more efficient than adding antimicrobials directly to the food. The antimicrobials migrate selectively and gradually from the film surface toward the surface of the food, and therefore maintain a high concentration of antimicrobial at the food surface for extended exposure (Ouattara and others 2000). Antimicrobial substances incorporated into edible films can control microbial contamination of fruits and vegetables by reducing the growth rate of target microorganisms, or by inactivating microorganisms by direct contact.

Most of the existing methods for testing the antimicrobial activities of substances require direct contact between the active agent and the microorganism (i.e., food), and thus are not relevant to many commercial products in which there is little or no direct contact between the food and the packaging material (Rodríguez and others 2007). Vapor phase tests, which are not direct contact assays, can be used to assess the protection provided by the antimicrobial volatile materials under no direct contact conditions.

One advantage of essential oils is their bioactivity in the vapor phase, a characteristic that makes them useful as possible fumigants for stored commodity protection. The antimicrobial activity of essential oils by vapor contact was first reported by Kellner and Kober (1954). They studied the effect of 175 essential oils in the gaseous state against eight airborne bacteria and fungi using an inverted petri plate technique (Maruzzella and Sicurella 1960). A volatile compound contained in a cup or on a paper disc was exposed to the inverted agar medium inoculated with a test organism. The size of the growth inhibitory zone after incubation is used as the measure of vapor activity. This technique is convenient for qualitative analysis, but not for quantitative comparison of the vapor activity of essential oils (Inouye and others 2003).

For components to evaporate and be classed as volatile it is imperative that there is a loss of weight over a time or temperature course (Fisher and Phillips 2008). The evaporation of the essential oils is effected by external factors such as temperature, humidity, concentration, and pressure (Aumo and others 2006). Volatile compounds from plants usually have a relatively high vapor pressure and are capable of interacting with an organism through the liquid and the gas phase (Fries 1973).

Storage temperature also influences the antimicrobial activity of chemical preservatives. Generally, increased storage temperature can accelerate the migration of the active agents in the film/coating layers, and refrigeration slows down the migration rate (Quintavalla and Vicini 2002).

## Methods to Measure the Antimicrobial Activity of Edible Films

Plant essential oils are a potentially useful source of antimicrobial compounds that can be incorporated into edible films. Factors such as the composition and solubility of the oil, bacterial strain, the sources of antimicrobial samples used, and the method of growing and enumerating the surviving bacteria can influence the determination of the antimicrobial activity of a plant oil (Friedman and others 2002; Zaika 1988).

Zone of inhibition assay (agar diffusion assay) is a commonly used method for the measurement of antimicrobial activity of edible films on solid medium. A recent study on the contribution of the vapors to the antimicrobial effects in direct disc diffusion method indicated that only the water-soluble components diffused across the agar while the redeposition of the vaporized components on the surface of the agar accounted for the remainder of the inhibition. It was found that for oils containing alcohol, ketone, ester, oxide, and hydrocarbons the major inhibition came from the vapors whereas for oils containing greater volumes of aldehydes inhibition came from diffusion (Inouye and others 2006).

Minimum inhibitory concentrations (MICs) of antimicrobial edible films can be assessed by the agar diffusion assay and observing the zone of inhibition, or the agar dilution method with visible growth observed, or broth dilution with visible growth, optical density, absorbance, or viable counts measured (Burt 2004). The MIC is determined as the lowest concentration at which growth is inhibited. The major problem with the method of determining the strength of antimicrobial activity of edible films is their hydrophobic nature, which makes them insoluble in water-based media (Fisher and Phillips 2008). Recently applied methods to evaluate the effect of antimicrobial edible films on the inhibition of human pathogens are shown in Table 12.1.

**Table 12.1.** Effects of edible antimicrobial films on the inhibition of human pathogens

| Base Material for Films | Target Pathogens Antimicrobial | Antimicrobial Agent | MIC[a] | References |
|---|---|---|---|---|
| Whey protein isolate (WPI) | *E. coli* O157:H7 | Oregano oil | 2 %w/v | Seydim and Sarikus 2006 |
| | *Staph. aureus* | Garlic oil | 3 | |
| | *S.* enteritidis | Rosemary oil | >4 | |
| | *L. monocytogenes* | | | |
| Alginate-apple puree | *E. coli* O157:H7 | Oregano oil | 0.1 %w/v | Rojas-Graü and others 2007a |
| | | Carvacrol | 0.1 | |
| | | Lemongrass oil | 0.5 | |
| | | Citral | 0.5 | |
| | | Cinnamon oil | 0.5 | |
| | | Cinnamaldehyde | 0.5 | |
| Pectin-apple puree | *E. coli* O157:H7 | Oregano oil | 0.08 %w/v | Rojas-Graü and others 2006 |
| | | Lemongrass oil | 0.5 | |
| | | Cinnamon oil | 0.5 | |
| Alginate | *E. coli* | Garlic oil | >0.4 %v/v | Pranoto and others 2005 |
| | *S.* typhimurium | Garlic oil | >0.4 | |
| | *Staph. aureus* | Garlic oil | 0.2 | |
| | *B. cereus* | Garlic oil | 0.1 | |
| Yam starch[b] | *S.* enteritidis | Chitosan | 3 | Durango and others 2006 |
| Alginate-apple | *E. coli* O157:H7 | Citral oil | 0.5 %w/w | Rojas-Graü and others (2007b) |
| | | Lemongrass oil | 0.5 | |
| Chitosan | *L. monocytogenes* | Chitosan | >1 %w/v | Coma and others 2001 |
| Chitosan | *E. coli* O157:H7 *L. monocytogenes* | Anise oil | 4 %w/w | Zivanovic and others 2005 |
| | | Basil oil | 4 | |
| | | Coriander oil | 4 | |
| | | Oregano oil | 1 | |

[a]Concentration in film solution.

[b]Method for testing inhibition was growth curve; all other tests were by zone of inhibition assay.

## Use of Edible Films and Coatings on Fresh Fruits and Vegetables

The most important quality attributes contributing to the marketability of fresh produce include appearance, color, texture, flavor, nutritional value, and microbial safety. These quality attributes are determined by plant variety, stage of maturity or ripening, and the pre- and postharvest conditions (Lin and Zhao 2007). Fresh fruits undergo vigorous biological reactions after harvest because their respiration accelerates the natural loss of fruit tissue. Therefore, fruits tend to lose water at room temperature; change appearance, texture, and quality; and decrease in commercial value. For use on fresh fruits and vegetables, an edible film would include good barrier properties and be odorless, tasteless, and transparent. Edible polymer films may be formed as either food coatings or stand-alone film wraps and pouches. They have the potential use with food as moisture, gas, and/or aroma barriers. A list of applications of edible films on fresh fruits and vegetables is shown in Table 12.2.

Table 12.3 shows some examples of successful applications of antimicrobial edible coatings on fresh fruits and vegetables. Antimicrobial edible coatings are more promising to be used on fresh-cut fruits and vegetables than on fresh produce, except when the produce is commonly consumed without peeling like the fresh produce listed in Table 12.3. Surprisingly, little research has been done on applications of antimicrobial coatings to melons or tomatoes, both of which have been reported in several major foodborne pathogen outbreaks.

The potential benefits of using edible films and coatings in the fresh produce industry include providing a moisture barrier on the surface of produce to decrease moisture loss; providing a sufficient gas barrier to control gas exchange between the fresh produce and its surrounding atmosphere to slow respiration, delay deterioration, and protect the fresh produce from brown discoloration and texture softening during storage; restricting the loss of natural volatile flavor and color compounds from the fresh produce or the acquisition of foreign odors by providing gas barriers; protecting produce from physical damage caused by mechanical impact, abrasions, pressure,

**Table 12.2.** Application of edible films on fresh fruits and vegetables

| Product | Application | Film Materials | Functions | References |
|---|---|---|---|---|
| Strawberry | Wrap, pouch | Wheat gluten-based films | Retention of firmness, reduced weight loss, and maintained visual quality during storage | Tanada-Palmu and Grosso 2005 |
| Apple | Wrap | Apple-based edible films | Reduced moisture loss and browning in fresh-cut apples | McHugh and Senesi 2000 |
| Lettuce | Wrap | Biodegradable protein film | Did not show any beneficial effects on pectic substances and pigments | Schreiner and others 2003 |
| Green pepper | Wrap | Polylactic acid–based biodegradable film | Can be used to maintain quality and sanitary conditions in modified atmosphere packaging | Koide and Shi 2007 |

Table 12.3. Application of antimicrobial edible coatings on fresh fruits and vegetables

| Product | Antimicrobial | Film Materials | Functions | References |
|---|---|---|---|---|
| Strawberry | Potassium sorbate/citric acid | Corn and potato starch | Inhibition of coliforms growth, extending shelf life for 14 days | García and others 1998 |
| Strawberry | Chitosan | Chitosan, lactic acid, and sodium lactate | Controlling decay and psychrotrophic food pathogens | Devlieghere and Debevere 2004 |
| Table grape | Aloe vera | Aloe vera | Extended shelf life up to 31 days and reduced initial mesophilic aerobic count | Valverde and others 2005 |
| Cherry | Aloe vera | Aloe vera | Extended shelf-life, improved sensory and chemical quality, and reduced initial mesophilic aerobic count | Martinez-Romero and others 2006 |
| Apple | Malic/lactic acid | Soy protein isolate and glycerol | Inhibited growth of pathogenic bacteria and extended shelf life | Eswaranandam and others 2006 |
| Quince | Ascorbic acid | Semperfresh (sucrose esters of fatty acids (FA), sodium carboxymethyl cellulose, and FA monodiglycerides) | Extended shelf life up to 31 days and reduced initial mesophilic aerobic count | Yurdugül 2005 |
| Carrot | Turmeric | Casein, polyvinyl, and propylene gylcol alcohol | Inhibition of coliforms growth extending shelf life for 7 days | Jagannath and others 2006 |
| Lettuce | Chitosan | Chitosan, lactic acid, and sodium lactate | Controlling decay and psychrotrophic food pathogens | Devlieghere and Debevere 2004 |
| Cabbage leaf | Lemon, orange, and bergamot essential oils | Lemon, orange, and bergamot essential oils | Reduce 5–6 log microbial loads Gram-positive and Gram-negative bacteria (*Campylobacter jejuni, L. monocytogenes, B. cereus, and S. aureus*) | Fisher and Phillips 2006 |

vibrations, and other factors; and acting as carriers for other functional ingredients, such as antimicrobial compounds, antioxidant agents, phytochemicals, colorants, and flavor ingredients for reducing microbial loads, delaying oxidation and discoloration, and improving quality and shelf life of fresh produce (Lin and Zhao 2007).

## Summary

The use of edible films and coatings as carriers of natural antimicrobials (such as plant essential oils) constitutes an approach for external protection of fruits and vegetables to reduce surface microbial populations and to enhance oxygen-barrier properties, potentially increasing food safety as well as shelf life of highly perishable foods such as fresh and fresh-cut fruits and vegetables. Appropriately formulated edible films and coatings can be utilized for fresh produce to meet challenges associated with stable quality, market safety, nutritional value, and economic production cost.

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